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# TESTS OF THE EFFECTS OF A SPREAD SPECTRUM SIGNAL ON RADARS

## Introduction

As a part of our participation in the exploration of packet radio networks, SRI is performing a series of r.f. channel measurements. This series includes tests involving the transmission and reception of spread-spectrum signals in the 1- 2 GHz band to measure the channel impulse-response.

On January 7 and 8, 1974, a series of tests were made to determine the effect of these spread-spectrum signals on two nearby radar systems. The radars were an Air Force AC&W search radar at Mt. Tamalpais and an FAA in-flight surveillance radar at Scarper Peak. This report describes the tests.

## Description of Tests

### General

To facilitate channel measurements, SRI has recently modified a 14-foot GMC step-van to operate as a mobile laboratory. A packet-radio test transmitter, constructed for ARPA by Collins Radio Corporation and described in another temporary packet radio note was installed in the van for these tests. Dr. R. Kahn (ARPA) monitored the tests and observed the effects of interference on the Air Force radar at Mt. Tamalpais. Dr. D. Nielson (SRI) directed the tests from the van, and Dr. S. Fralick (SRI) observed the effects of interference on the FAA radar at Scarper Peak. We very much appreciated the help of Mr. R. Young (FAA site engineer) and M/Sgt. Jensen (Air Force) who acted as a test control group to assure that the tests would not cause operational problems.

The tests were performed by transmitting spread-spectrum signals from two sites (one site each day) and simultaneously observing the

PPI (Plan Position Indicator) and A-scope displays at the two radar sites. For various logistic and security reasons, it was possible to photograph the PPI display at the FAA site only.

## Geography

The geography of the tests is shown in Figure 1. The FAA radar is located at Scarper Peak, the Air Force radar is located at Mt. Tamalpais, and the transmitter sites were at Vista Point on Highway 280 and Twin Peaks in San Francisco. Elevations and distances are shown in Figure 1.

## Transmitted Signal

The signal transmitted was a 6-watt spread-spectrum signal generated by the Collins packet radio test set. This test set generates a binary-valued non-return-to-zero pulse train from a 127 chip maximal-length sequence generator. The nominal chip rates are 10 and 20 megachips/sec. Each 127-chip sequence is called a bit, so the nominal bit-rate is about 80 and 160 kilobits/sec. Various bit-sequences are possible, but for most of the tests a continuous bit-sequence of 1's was used, so that the chip-sequence was repeated every 127 chips.

To transmit the signal a chip-sequence is used to biphase modulate a carrier at 1325 MHz. The biphase modulated carrier is filtered to reduce the transmitted energy outside a nominal 40 MHz band centered at 1325 MHz. The transmitted spectrum is shown in Figure 2.

The test-set transmitter was modified by Collins just prior to the tests so that the duty-cycle of the transmitted signal can be controlled either automatically or manually. This control is essentially an on-off key with independent control of the duration and repetition rate of the "on" periods. During an "on" period, the transmitter radiates a number of code sequences determined by the test-set controls.

Two antennas were used in the test. One is an omni-directional antenna with nominal gain 2 dB. The other is a horn with nominal gain of 13 dB whose pattern is shown in Figure 3.

DISTANCES (km)

| | SCARPER PK. | MT. TAM |
|---|---|---|
| TWIN PEAKS | 22.5 | 21 |
| VISTA POINT | 8 | 48 |

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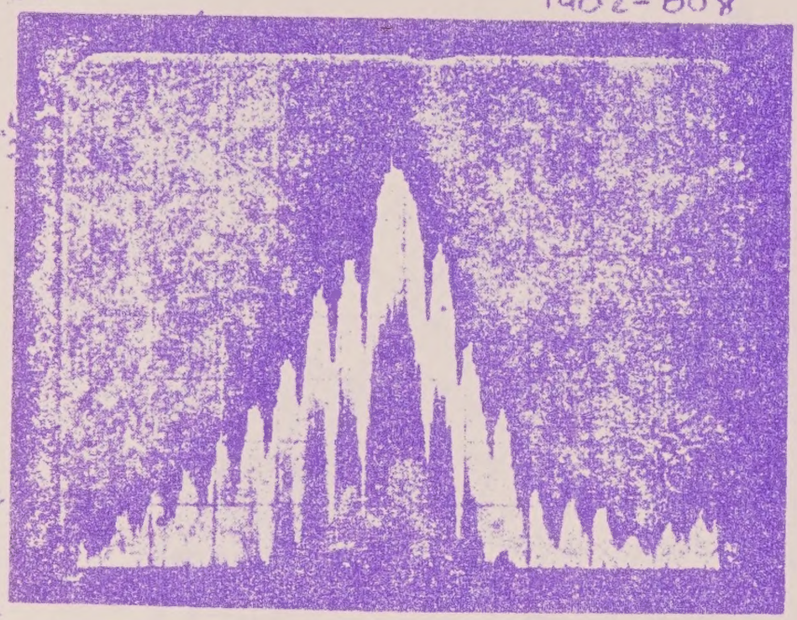
# TRANSMITTER SPECTRUMS CON'T 1325MHZ

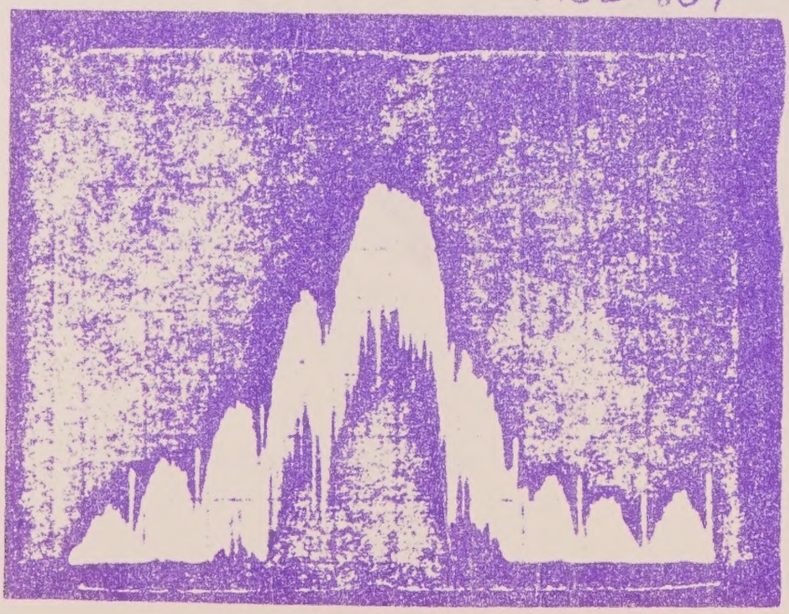
XMTR → 30DB → SPECTRUM ANALYZER

10M CHIP CONTINUOUS CODE MODE

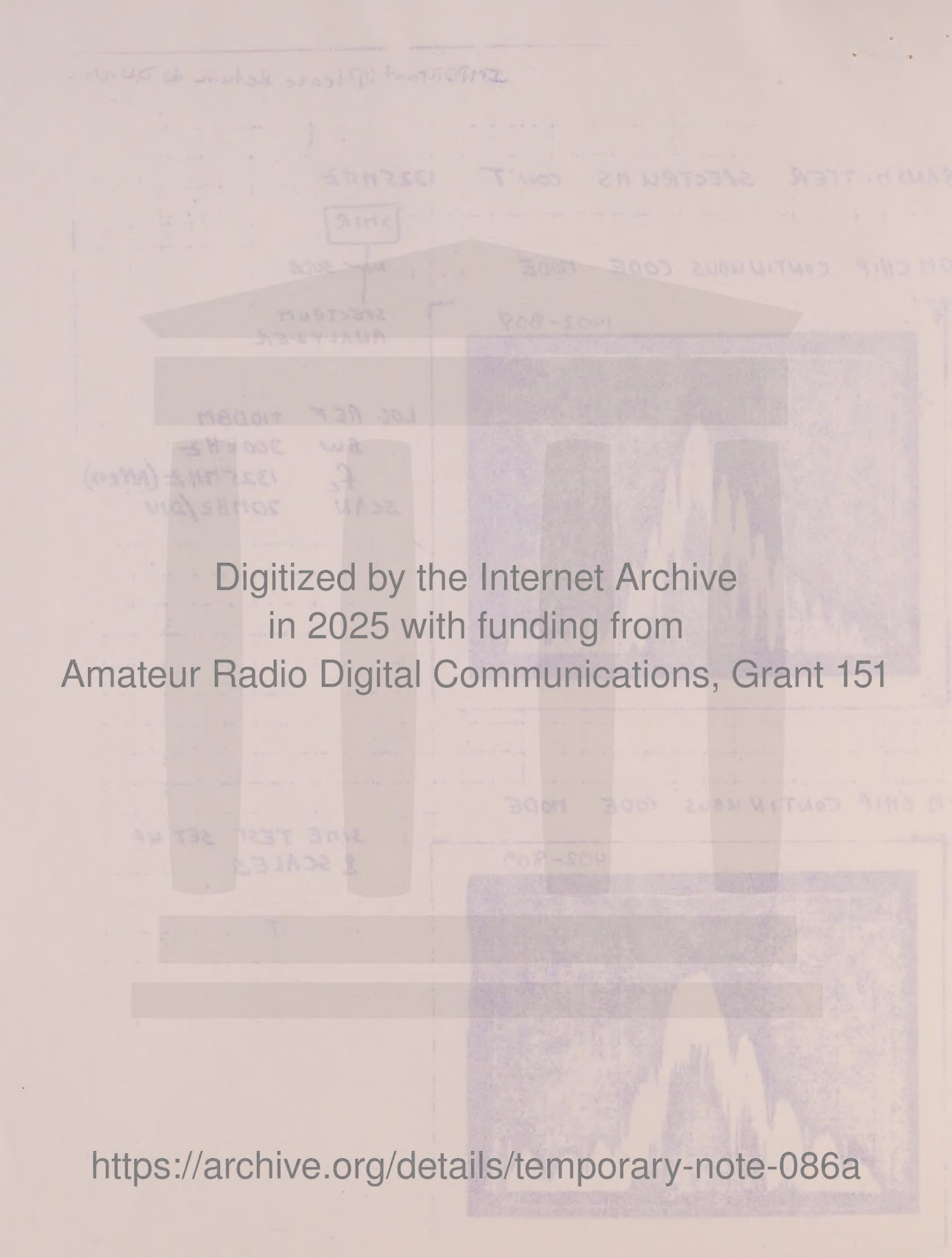



LOG REF +10DBM
BW 300kHz
$f_c$ 1325MHZ (APPROX)
SCAN 20MHZ/DIV

20M CHIP CONTINUOUS CODE MODE




SAME TEST SET UP & SCALES



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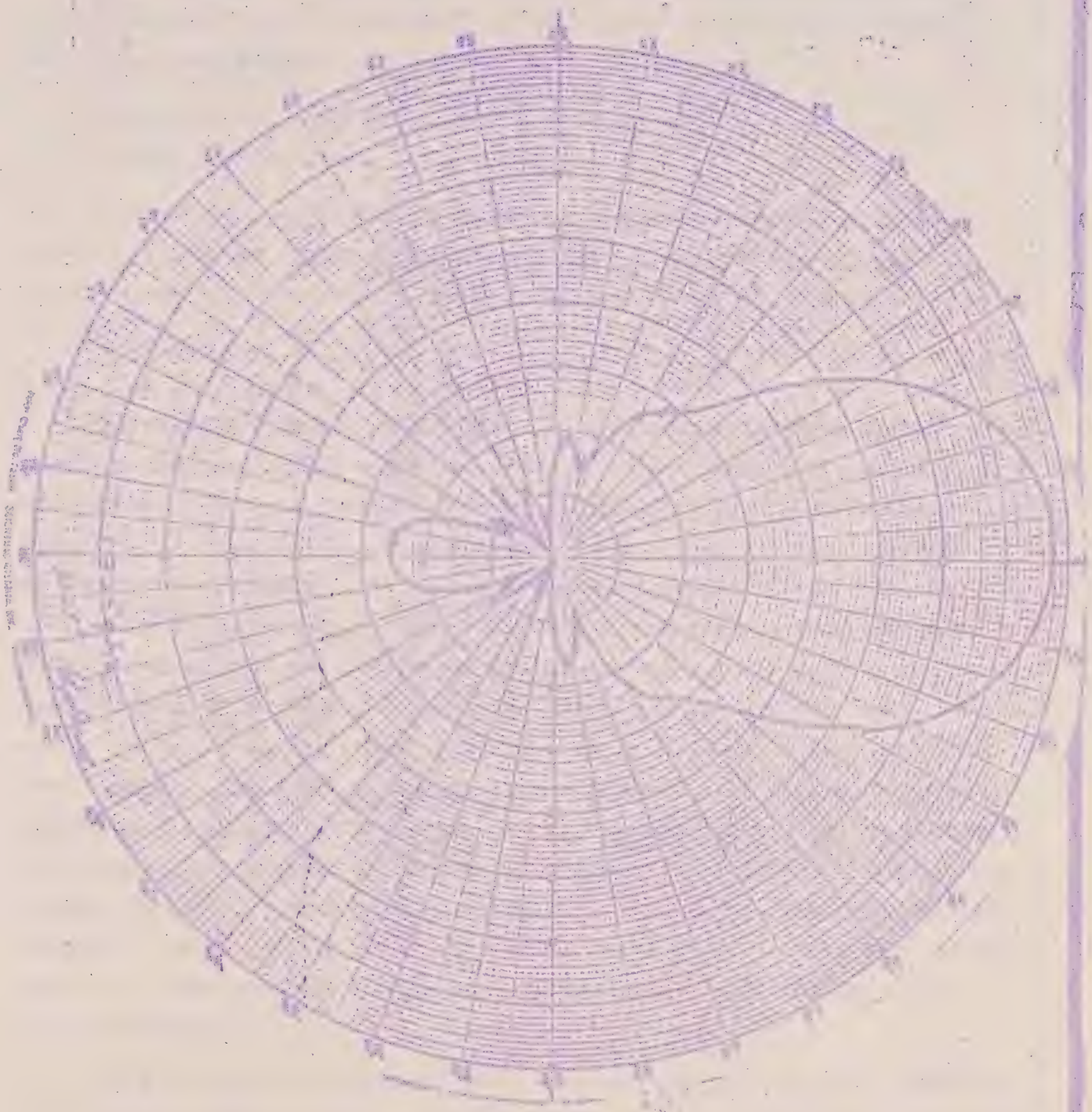


Radar

The FAA radar is a general-search radar used for in-flight surveillance. During tests it was tuned to 1338 MHz. It transmits a 2 μs pulse with 4 MW peak-power on an antenna with 34 dB gain. The prf is nominally 333 pps. The receiver bandwidth is nominally 3 MHz.

If we assume a noise figure of 5 dB, then the receiver noise-level should be about -106 dBm referred to the antenna terminals or -140 dBm including antenna gain.

The Air Force radar is similar in all respects; however, precise details were not available.

Both radars are used to detect and track aircraft in flight. The antenna is rotated approximately five times per minute, and the raw-video return is processed digitally and displayed to flight controllers for the FAA.

The raw-video return at the FAA site was observed both on a plan-position-indicator (PPI) and on an A-scope. The A-scope is a standard oscilloscope with the horizontal sweep synchronized with the transmitted pulse train. The vertical displacement is proportional to the envelope of the received signal. Hence targets appear as pulses which occur at a time proportional to range. They will appear and disappear as the radar antenna sweeps past the target and illuminates it. Noise appears as random pulses which look somewhat like grass. An interfering signal, unsynchronized with the radar will raise the general noise level and may mask targets. The level of the interfering signal will vary with the direction the antenna points since it will be proportional to the gain of the antenna in the direction of the interfering transmitter. Although the A-scope is a good indicator of interference, and can provide some absolute measure of intensity, it does not provide the long-time integration effect seen by a radar observer, so it does not completely describe the effect of interference.

The plan-position-indicator (PPI) is a CRT display with the electron-beam position swept along a radial line, synchronously with the transmitted

pulse so that the position of the beam radially from the center of the CRT is proportional to the range.

The PPI is a polar-coordinate display of the received video (r.f. envelope) signal. The electron beam is swept radially, once for every transmitted pulse. The azimuth of the radial sweep is continuously increased in synchronism with the angular sweep of the antenna. The beam is intensity-modulated with the received video, so that a pulse will cause a bright spot on the phosphor. The phosphor persistance is usually set so that the bright spot fades almost completely in one complete antenna sweep. Targets appear on the PPI as a bright dot at an azimuth and range from the CRT center, proportional to true azimuth and range from the radar antenna. Noise appears as random bright dots on the screen.

The appearance of an interfering signal on a PPI depends on the strength and duration of the signal, and on the antenna direction when the signal is sent. For example, a 1 ms burst which was transmitted with sufficient amplitude to exceed the noise level would appear as a radial-line segment on the PPI. The length of the line would depend on the CRT sweep speed. If the sweep speed was adjusted so that the total radius (approximately four inches) = 300 miles, then the beam would be swept radially at a rate of 1.33 inches/ms. A 1 ms signal burst would appear as a line 1.33 inches long. A 100 μs burst would appear as a line .13 inches long.

Interfering signals which last longer than one inter-pulse period will be displayed as a sequence of bright radial lines which sweep out a pie-shaped segment of full radial-length and angular spread equal to 360 d/12 degrees where d is signal duration in seconds.

As the interference amplitude level decreases, the brightness of the display will decrease (within the phosphor dynamic range) until the line will no longer be continuous, but will be a sequence of dots, and finally will disappear altogether. The amplitude level will change as the antenna rotates, so that we would expect maximum brightness of the display when the antenna points in the direction of the interfering transmitters and

darkness when antenna-pattern nulls point toward the transmitter. These effects were all demonstrated during the tests and are illustrated later.

## Test Procedure and Results

On February 7 the packet radio transmitter was set up at Vista Point on Highway 280 (see Figure 1).

Our first objective was to determine if we could radiate low duty-cycle, full power signals on the omni-antenna without interfering with the radars. To accomplish this we transmitted full-power spread-spectrum pulses and varied the pulse duration. Pulse durations of 120 μs and 1 ms were radiated once per second. The results of these tests are shown in Figures 4 and 5, 6. We also manually generated one-second bursts, and once generated a 15 second burst. The one second burst is shown in Figure 6. The 15 second burst is not shown.

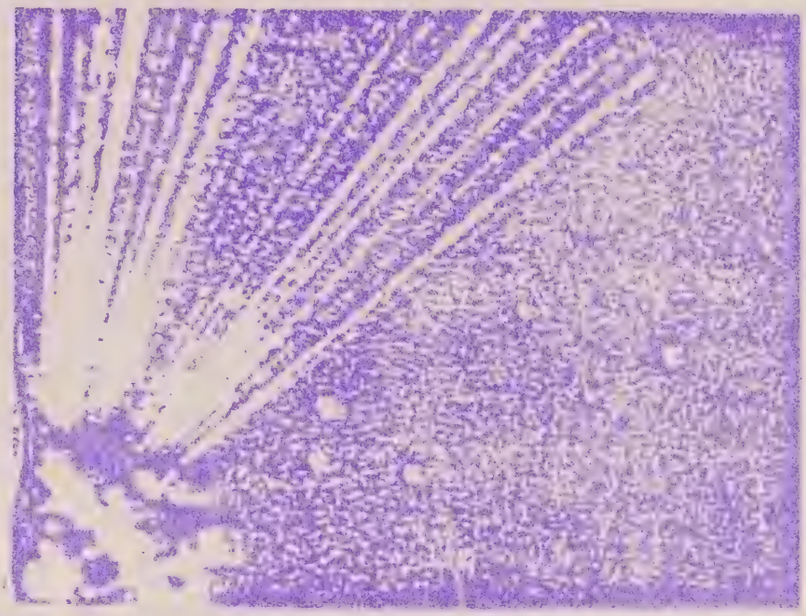
Figure 4 shows a triple exposure of the Scarper Peak PPI quadrant containing the azimuth of the transmitter. During this exposure we were transmitting 120 μs bursts. No interference was observed for this or any shorter duration test signal.

Figure 5 shows a triple exposure of the Scarper Peak PPI, same quadrant. During this exposure we were radiating 1 ms bursts of test signals. Although the interference is clearly visible, it does not appear to mask targets, or to be otherwise seriously objectionable.

Figure 6 shows a single exposure of the Scarper Peak PPI, Northeast quadrant. During this exposure we were radiating a one second burst. The variation in intensity is due to the fact that the antenna was pointed roughly at 90° to the test transmitter, and the interfering signal was being received on the antenna side lobes. Similar interference was noted on the back lobes. In fact, during the 15 second burst the entire PPI was illuminated with bright radial lines. It is clear that such interference would cause serious problems.

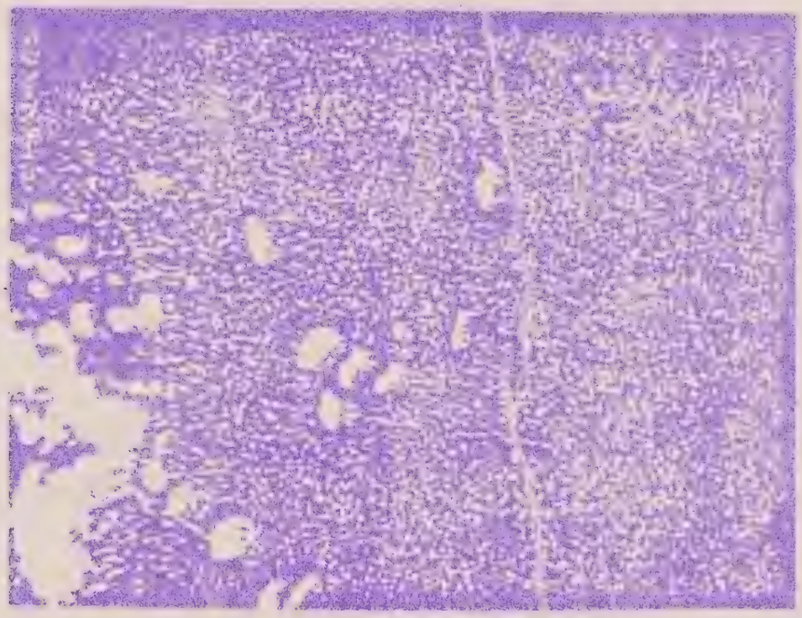
Our second objective was to determine the maximum power which we could radiate without interference. This was accomplished by radiating manually controlled pulses of ½-1 second duration, and attenuating the

TRANSMITTER AT VISTA PT., OMNI FULL POWER



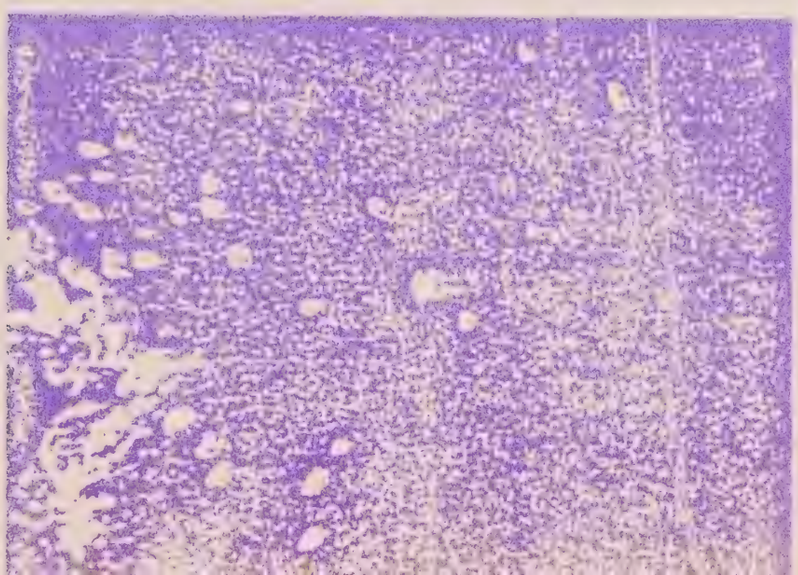
1 SEC. BURST

FIG 4.



1 ms BURST

FIG 5.



120 μs BURST

FIG 6.

power delivered to the test-transmitter antenna. The results of this series of tests are shown in Figures 7, 8, 9, and 10.

Figure 7 shows the effect of full-power bursts, Figure 8 shows the effect when 10 dB attenuation was inserted, Figure 9 shows 20 dB attenuation, and Figure 10 shows 22 dB attenuation. No interference was observed for attenuation in excess of 22 dB. Preliminary calculations of propagation loss indicate that the radar should receive a signal at the nominal r.f. noise level with 55 dB attenuation inserted. Since the background noise peaks are being displayed, one would expect to see interference down to 40-50 dB attenuation. This discrepancy has not been satisfactorily explained.

During these tests, no interference was observed at Mt. Tamalpais. Since Mt. Tamalpais was six times as far away as Scarper Peak, we expected the test signal to appear at Mt. Tamalpais with an attenuation of about 14 dB relative to Scarper Peak. This did not occur. When we transmitted the test signal using a horn antenna with 13 dB gain, pointed at Mt. Tamalpais, we still did not cause noticeable interference. The reason for this is unknown; however, it may be due to special MTI circuitry at Mt. Tamalpais.

On February 8 we repeated the tests with the transmitter located at Twin Peaks. The pulse-duration test results were the same as those of February 7.

Figures 11, 12, and 13 show the result of the power-level tests. In this case, the pictures are of the quadrant containing true North, hence the azimuth to the transmitter. So long as at least 13 dB of attenuation was inserted at the transmitter, no interference was observed. This is to be expected since the range to Twin Peaks is three times the range to Vista Point, so the propagation loss should be about 9 dB additional.

The radar at Mt. Tamalpais did not observe interference during this sequence.

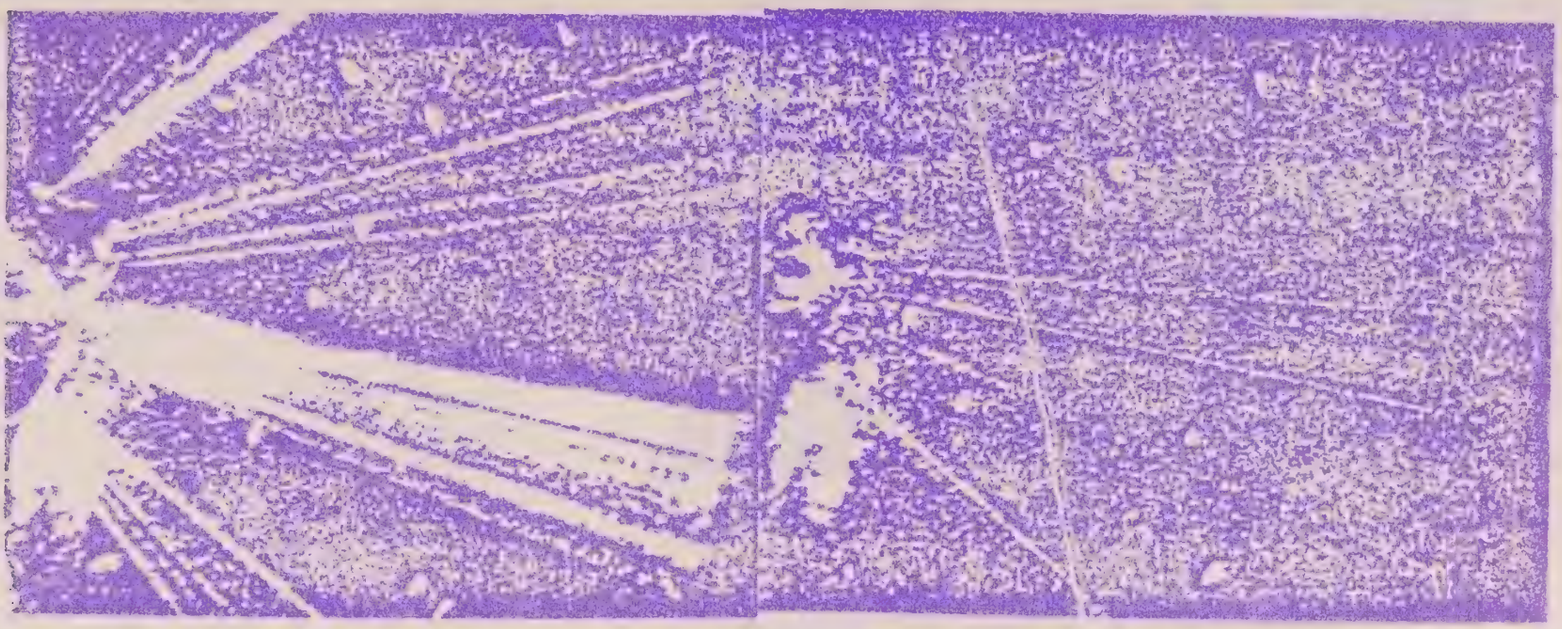


FIG 7.- FULL POWER

FIG 8.- -10 dB

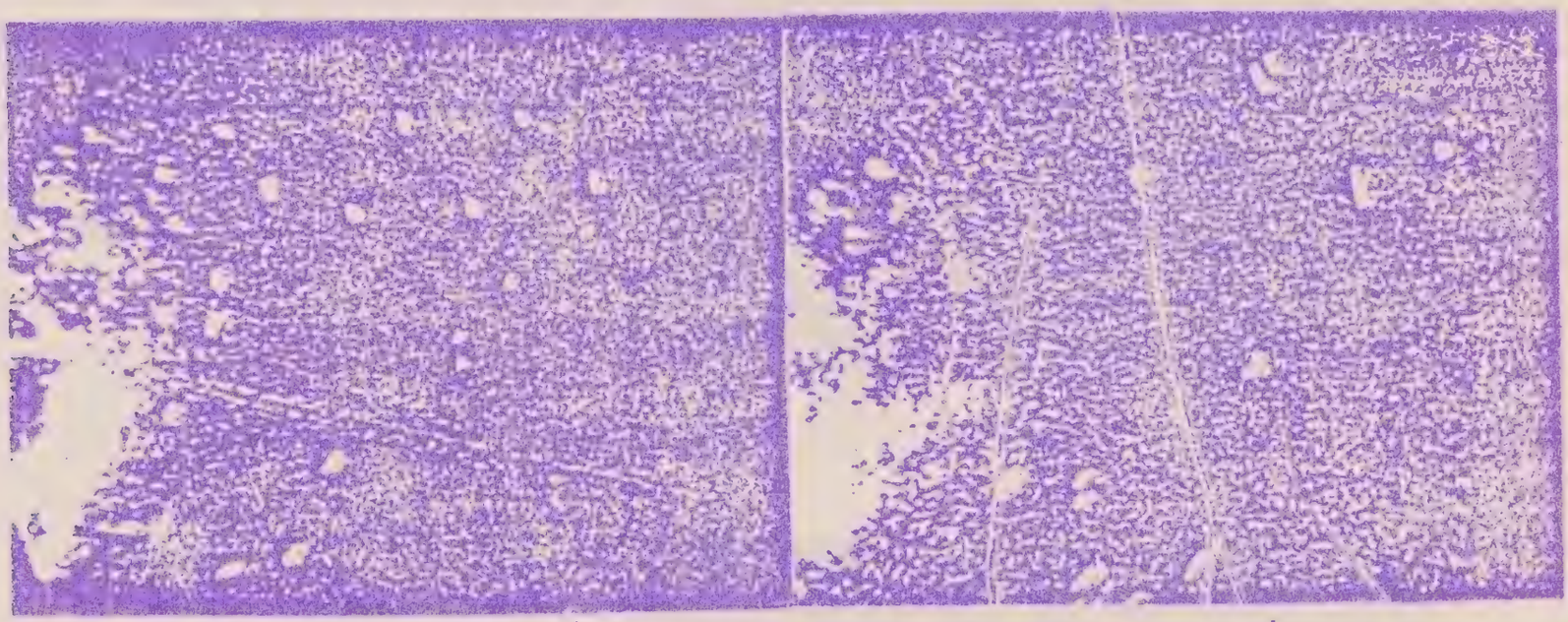


FIG 9.- -20 dB

FIG 10.- -22 dB

TRANSMITTER AT VISTA POINT, OMNI ANTENNA, FULL POWER. MANUALLY SWITCHED ON-OFF FOR 1/4 - 1/2 SEC INTERVALS.

TRANS. AT
TWIN PEAKS, OMNI
CONT. CODE

FULL POWER

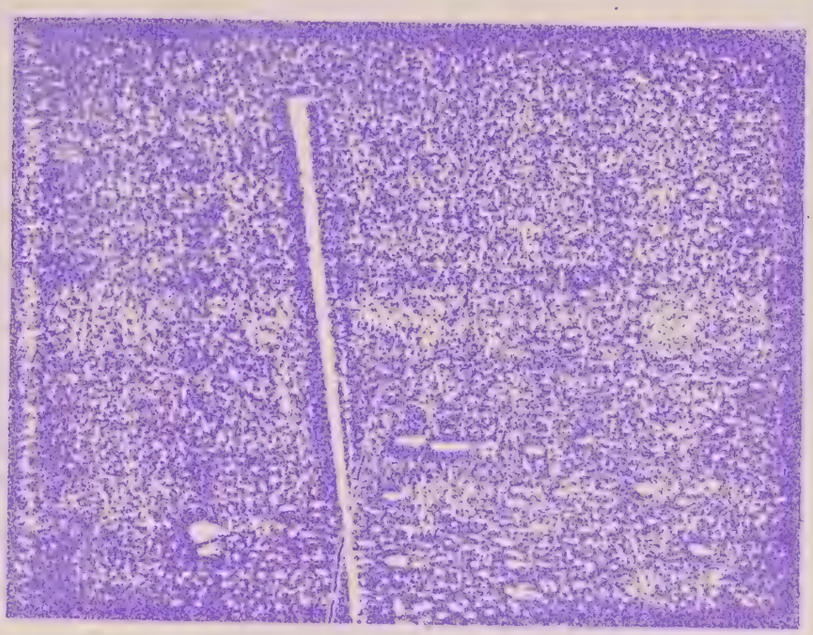


FIG 11.

-10 dB

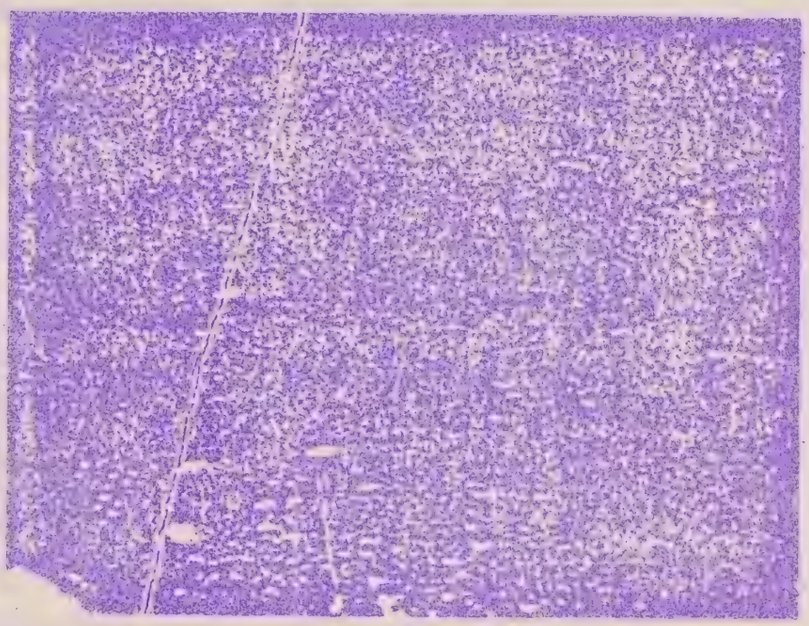


FIG 12.

-13 dB

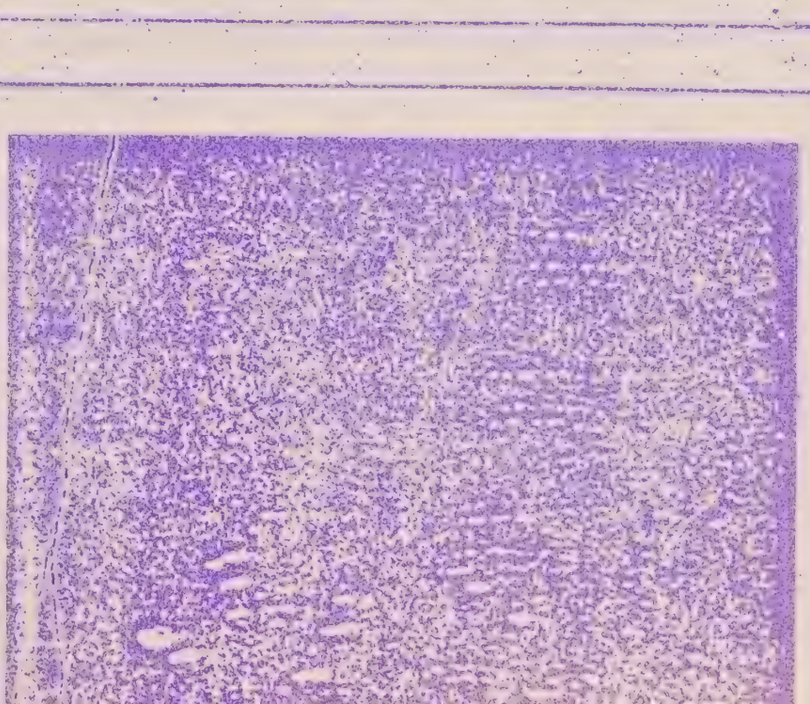
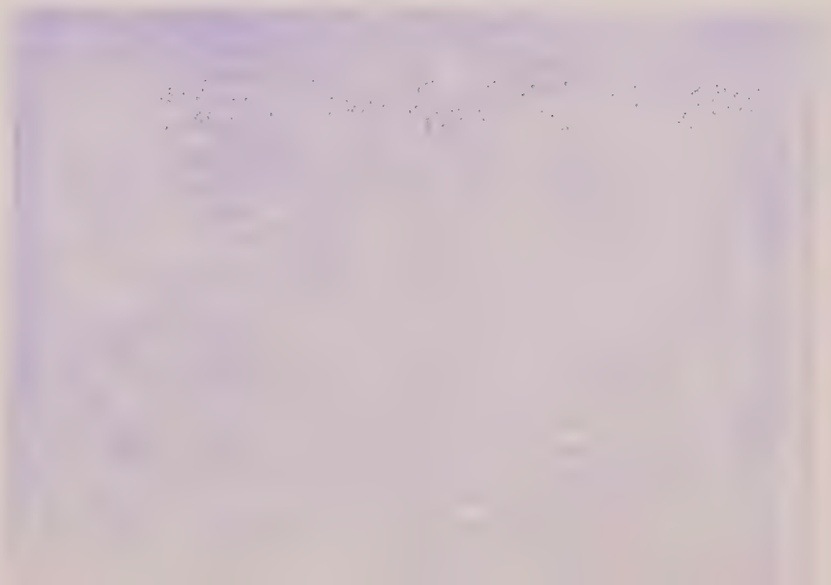


FIG 13.



In order to generate interference at Mt. Tamalpais, it was decided to radiate using the horn antenna, and pointing it directly at Mt. Tamalpais. Using 1 second manually-generated bursts, the interference was at last observed. No pictures of this effect were made.

Finally, to determine whether we could radiate using the horn at Twin Peaks to illuminate San Francisco without interference to Scarper Peak, we radiated full power with the horn, and rotated it to determine the "no-interference" limits with Scarper Peak. These were roughly a 140° arc pointed away from Scarper Peak. A picture of the interference at the 180° point is shown in Figure 14. To check for anomolous horn gain we inserted 20 dB attenuation and rotated the horn 360° while radiating ½ second bursts. The maximum interference occurred with the horn pointing at Scarper Peak. Results are shown in Figure 15.

## Conclusions

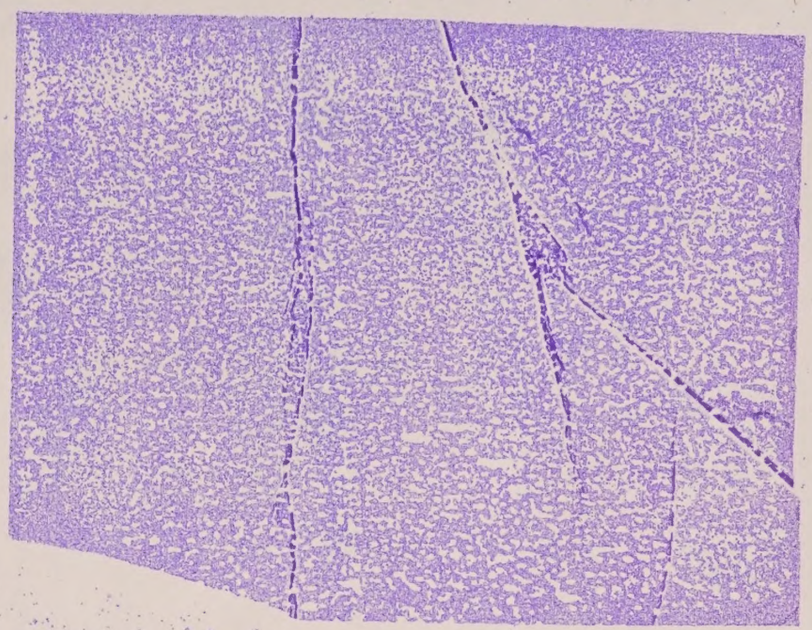
The results of these tests indicate that we can radiate enough energy for our propagation tests so long as we use bursts shorter than 120 μs once per second, or so long as we use a directional antenna which provides at least 13 dB (22 dB) attenuation in the direction of Scarper Peak from Twin Peaks (Vista Point).

We assume that for future propagation tests these results may be scaled for range using a propagation loss proportional to the inverse squares of range, and for frequency offset by considering the spectral energy density of the transmitted signal relative to that transmitted at 1338 MHz when the carrier is 1325 MHz.

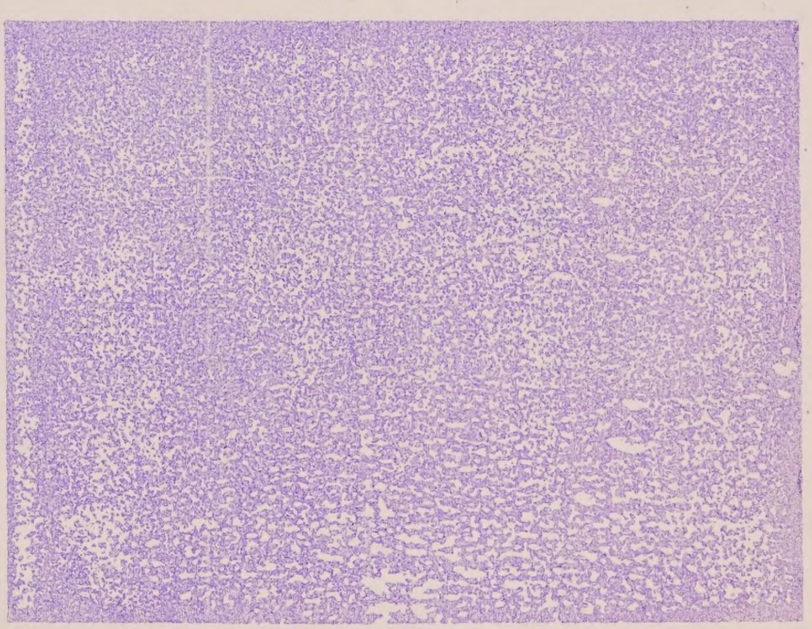
TRANSMITTER AT
TWIN PEAKS

HORN AIMED AT
SCARPER PK
WITH 20dB
ATTEN

FIG 14.



HORN, NO ATTEN.
AIMED AT SCARPER ± 90°

FIG 15.

NO NOTICEABLE EFFECT
FOR ALL AZ. BETWEEN
THESE LIMITS